ANALYSIS OF SUSTAINABILITY FACTORS FOR COMMERCIAL AND RESIDENTIAL BUILDINGS USING SOFT COMPUTING TECHNIQUES

A SYNOPSIS

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1. INTRODUCTION

Buildings are known to contribute to society's major environmental impact; sustainable practices that contribute to sustainable buildings have been known to balance the environment and sustainability in society Gilani [1]. Buildings are the major sources of energy consumption and possess the potential to create a positive impact on society if sustainable Qarnain et al., Qarnain et al. [2, 3]. The challenges faced by sustainable buildings are limited to cost, materials, technology, design and construction process and the factors that can holistically uplift sustainability Lasar and Chithra [4, 5]. The Scope of this research is to provide the list of sustainability factors for energy efficient buildings of commercial and residential sector of south Indian region.

Sustainability is defined as maintaining ecological balance without depleting natural resources while containing a society of healthy living beings in a habitat Mohammed et al., Bhatnagar et al. [6,7]. Sustainability is considered the core element of sustainable cities; therefore, also considered one of the UN's main goals in SDGs (Sustainable developmental goals) Lasar and Chithra [8].

The urban development in infrastructure consists mainly of residential and commercial buildings. The environment and local geographical climate are highly dependent on the anthropological activities in this region, and buildings are the main contributors to this Environmental depletion. To solve depletion in the local environment and replenish the sources, sustainability in buildings should be of prime importance. This proposed research provides factors that leverage sustainability in commercial and residential buildings because they contribute to most of the building topology in urban habitat—and focusing the majority of building topology on making these buildings sustainable to solve environmental degradation and improving geographical climate locally.

Commercial buildings are a source of significant energy consumption. According to a study by the U.S DoE world's 40% of energy use is by commercial buildings alone Noh et al. [9]. In India, Commercial buildings consume more than one- third of the total energy generated, representing 8% of the sectorial consumption and are growing 8% annually. This share is significant, next only to the industry share in

electricity consumption Kabre and Tyagi [10]. In 2017 Indian commercial sector accounted for about 1100 million m² of floor space and consumed 75TWh of electricity annually Qarnain et al. [11]. India's commercial built-up area increased from ~516 million m² in 2004-05 to 660 million m² in 2010. India is projected to reach a total built-up commercial floor space of 1900 million m² by 2030 Kabre and Tyagi [10] to meet increasing commercial space demand resulting from rapid urbanisation, emerging industrialization, and population immigration.

Therefore, energy efficiency leading to sustainability in commercial and residential buildings should be of prime importance. This research presents factors that can bring energy conservation in buildings by controlling energy consumption. There exists a strong correlation between the factors of energy consumption in a commercial building. In other words, the factors are a set of control points from where energy consumption can be strategically increased or decreased. The factors can act as a powerful tool for assessing energy in the Indian buildings sector Imam and Banerjee [12].

This research provides answers to the following research hypothesis questions:

1. Does there exist factors that can improve sustainability in commercial and residential buildings in urban habitat?
2. Can the factors are prioritized and ranked so that implementation could be achieved for the most important factors?

This research was conducted specifically for the south Indian context as the decision-makers and input to the models are provided by experts were from south India.

This research work tries to answer the following research questions:

a) What are the factors that are responsible for energy consumption in commercial and residential built-in spaces?

b) Which is the most prioritized and least prioritized factors among the comprehensive list of energy factors?

2. LITERATURE SURVEY AND RESEARCH GAP

There is a huge potential unexplored in saving energy in the Indian commercial sector Garg et al. [13]. Energy is a fundamental necessity of commercial and residential building for its day-to-day operations and activities leading to sustainability. Novel technologies are being introduced to optimize building energy consumption in recent times Qarnain et al. [11]. According to the Global building performance network, the GHG and energy consumption of buildings in India will increase by 700 percent in 2050 compared to 2005 levels. Most of the energy consumption factors in Indian office buildings or commercial buildings are related to the comfort of the building occupants Tewari et al. [14]. With a population of over 1 billion people and a rapidly growing construction industry, India accounted for more than a third of all electricity produced annually. Most of the electricity is wasted in buildings because most of the vital factors for energy consumption are neglected. Some of the factors responsible for energy wastage in Indian buildings are building orientation and large glazing without shading Bano and Sehgal [15].

This proposed research work presents a set of factors directly from the end-users of energy and commercial building occupants responsible for a commercial and residential building energy consumption.

Research factors to control Indian commercial buildings' energy consumption are ascertained because there are no official classifications of the Indian commercial and residential building sector. The need for this research is reaffirmed because of the following prevalent gaps in the existing literature:

a) The data for energy consumption for the commercial and residential sector in India is not institutionalized and not segregated.
b) Few attempts were made to find factors for commercial building energy consumption in India.
c) There is no systematic data collection technique for commercial and residential buildings. It is done on an ad hoc basis Kumar et al. [16].

This research provides insight into the factors responsible for energy consumption and tries to minimize the prevalent literature gap. Most of the existing literature on energy

consumption factors focuses on the residential and industrial sectors. The study for finding the factors for Indian commercial buildings is rare in prevailing literature. Therefore, this research was conducted to fill the existing literature gap and leverage energy conservation by providing factors that can control energy consumption leading to sustainable practices in Indian commercial and residential spaces.

Most of the contemporary research works that have used MCDM methodology have focused on different smart cities' different indicators and criteria. But, the focus on energy indicators of building energy consumption is found to be scarce. This proposed research work has used MCDM methodology to evaluate energy efficiency factors in buildings. The research gap identified is depicted in Figure 1.

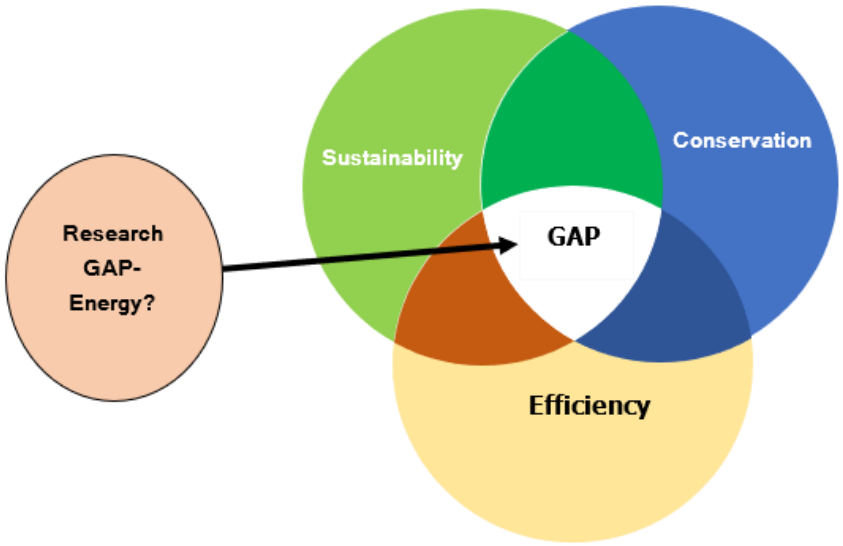

Figure 1 Identification of Research Gap

3. RESEARCH OBJECTIVES

This research was conducted to achieve the following research objectives: -

1. To establish the need and necessity of energy saving factors for buildings in a commercial and residential society.
2. To arrive at factors are that responsible for saving energy in commercial and residential buildings in a society.
3. To differentiate the factors into main domains for further analysis and study.
4. Analysis of Energy efficiency factors from Building Energy Standards

The research objectives are depicted in Figure 2.

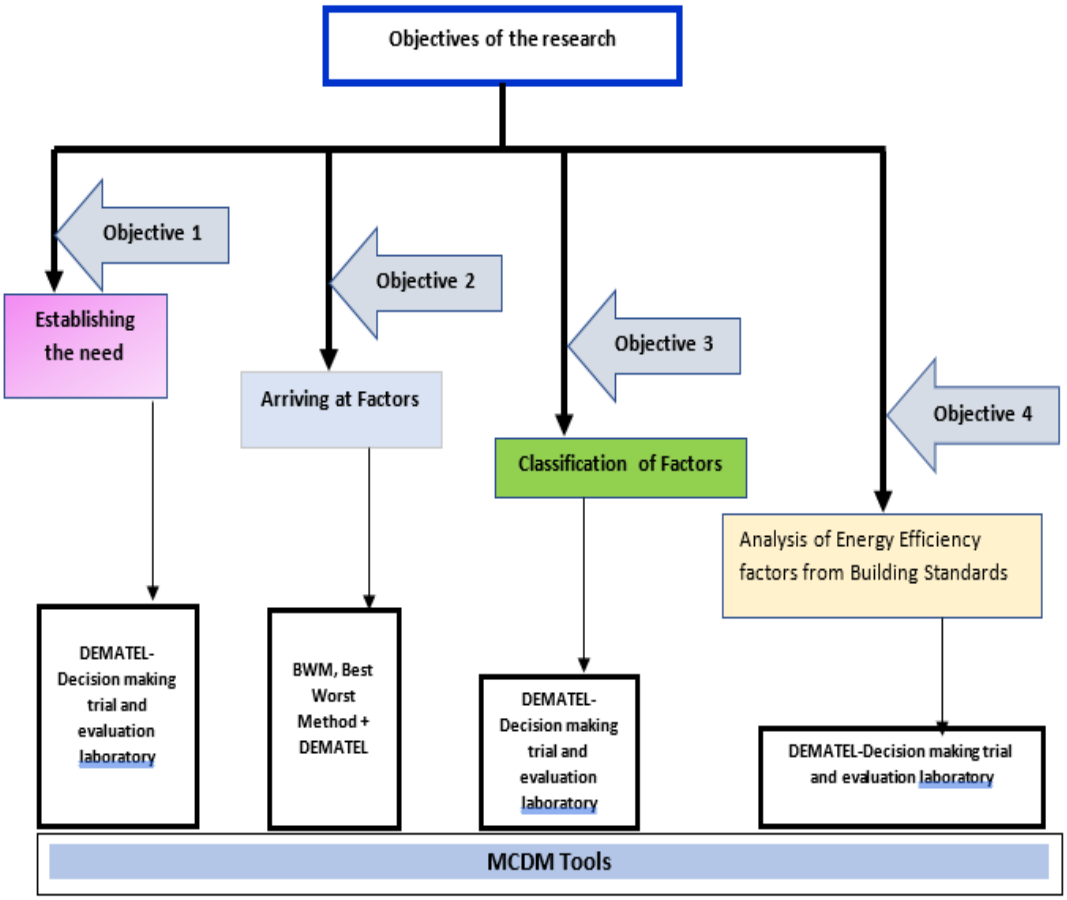

Figure 2 Research Objectives

4. RESEARCH PROBLEM

The urban quarter in India has always seen an ever-increasing rise in electricity consumption resulting in high utility bills especially in commercial and residential building sector. There is often a displeasure among the building owners about the rise in energy tariff that they pay to energy supplying companies. To decipher the problem of high energy consumption the authors of this research felt a need to explicatively analyze the cause of high energy consumption in commercial and residential building sectors of india. The residential sector is a non-commercial sector and the electrical utility bill is a burden on the family income. Whereas in the commercial building sector it is a burden to building owners because primarily, the tariff is commercialised and higher than other sectors, Secondly, the utility bills eat away the profits of the commercial organisation. There was a need to find what are the factors that causes rise in energy demand of

buildings. This motivation prompted an attempt to find factors that necessitate the energy rise in buildings. if the priorities and their relevance are known it could lead to better understanding of the causes and help the strategy makers to reduce the energy consumption by buildings on a national scale.

5. RESEARCH FRAMEWORK

5.1 What is Empirical research?

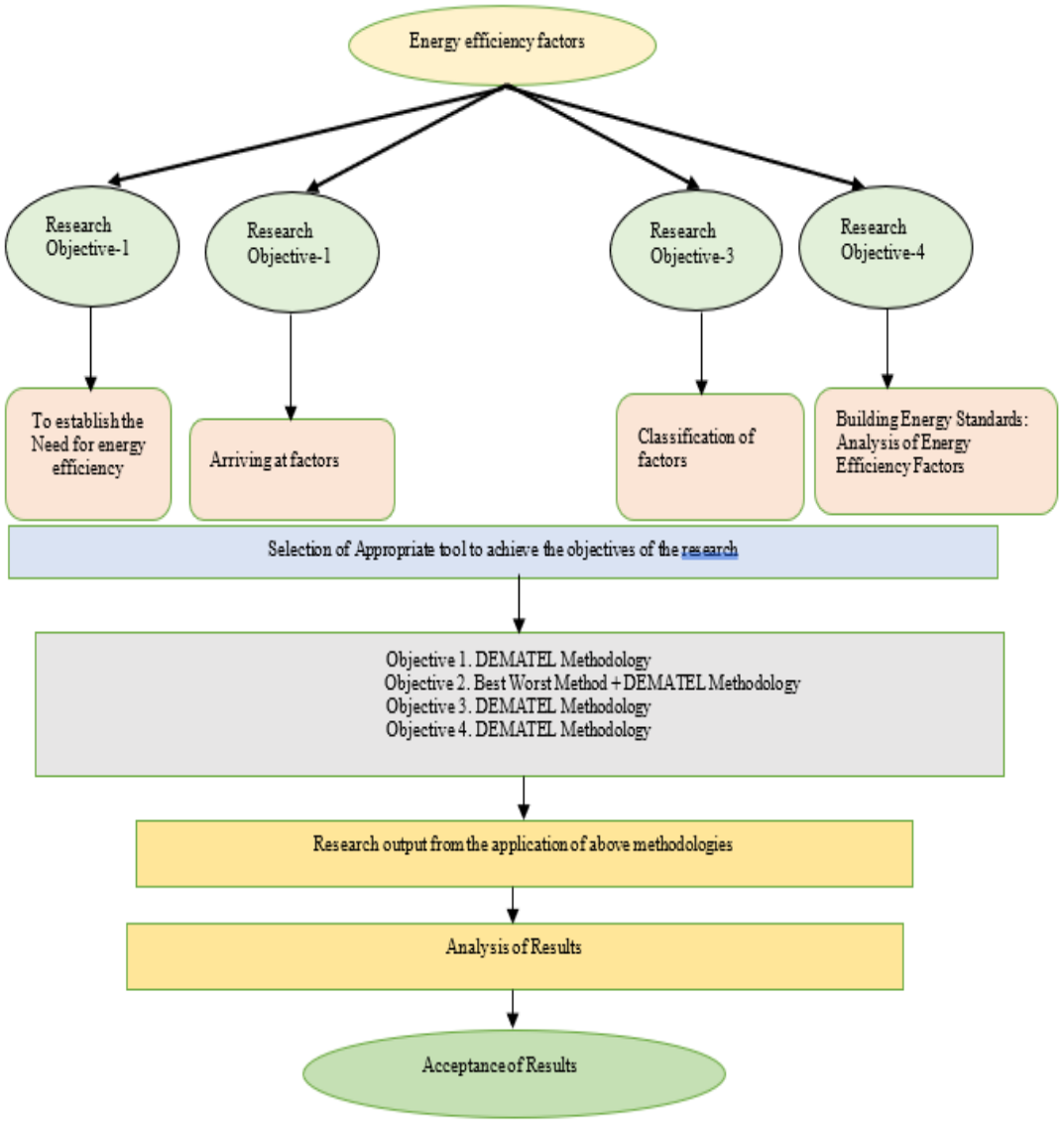
Energy efficiency factors
Research Objective-1
Research Objective-1
Research Objective-3
Research Objective-4
To establish the Need for energy efficiency
Arriving at factors
Classification of factors
Building Energy Standards: Analysis of Energy Efficiency Factors
Selection of Appropriate tool to achieve the objectives of the research
Objective 1. DEMATEL Methodology
Objective 2. Best Worst Method + DEMATEL Methodology
Objective 3. DEMATEL Methodology
Objective 4. DEMATEL Methodology
Research output from the application of above methodologies
Analysis of Results
Acceptance of Results

Figure 3 Research Framework

Empirical research is research that is based on observation and measurement of phenomena, as directly experienced by the researcher. The data thus gathered may be compared against a theory or hypothesis, but the results are still based on real life experience. The data gathered is all primary data, although secondary data from a literature review may form the theoretical background Tewari et al. [14].

On the other hand, empirical research relies on experience or observation alone, often without due regard for system and theory. It is a research, coming up with conclusions which are capable of being verified by observation or experiment. Evidence gathered through experiments or empirical studies is today considered to be the most powerful support possible for a given hypothesis Bano et al. [15].

As this is empirical research that explains the real on ground scenario, the general research design is depicted as in Figure 3.

6. RESEARCH METHODOLOGY

6.1 DEMATEL Methodology

Decision making trial and evaluation laboratory (DEMATEL) is a Multiple decision-making technique to establish energy efficiency factors and to understand the interrelation ship among the factors. This Methodology has the capability to differentiate the energy efficiency factors into Cause energy factors and effect energy factors. It can bring out the interlinking and interdependencies of in energy efficiency factors with the help of a Causal diagram. The various steps followed in the application of DEMATEL methodology are provided in Figure 4. The research framework followed is also provided in Figure 4. The energy expert panel is constituted and inputs are taken from the experts' panel. These opinions and decisions are then incorporated into DEMATEL framework to get the results.

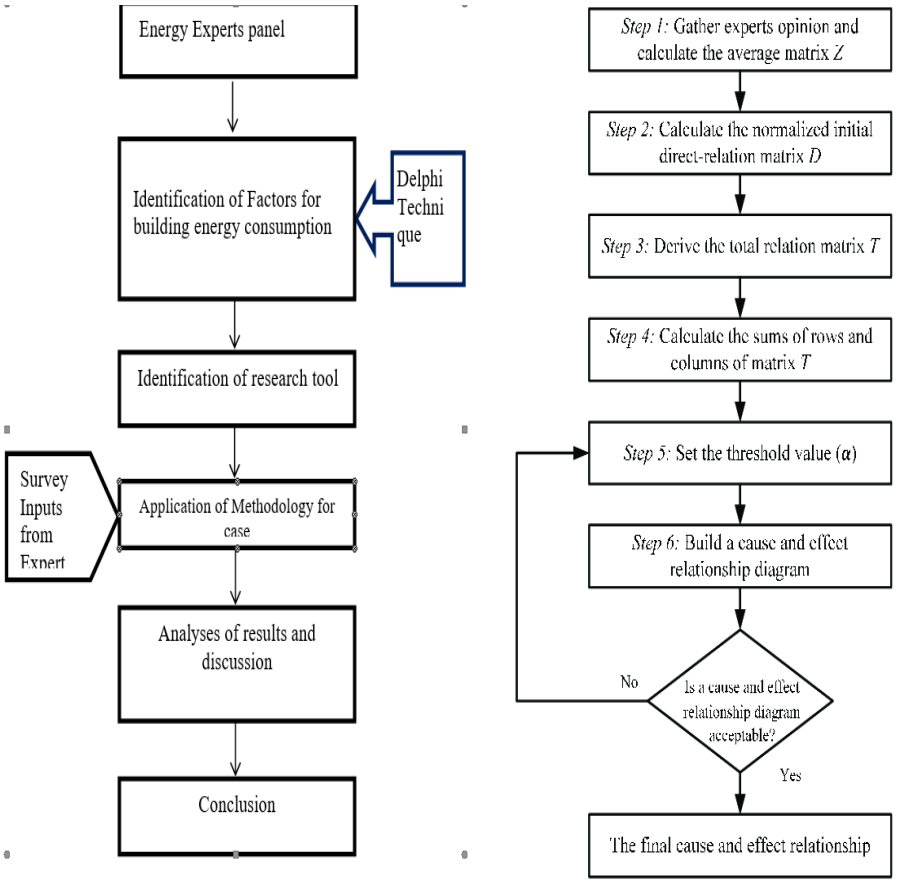
Energy Experts panel
Identification of Factors for building energy consumption
Delphi Techni que
Identification of research tool
Survey Inputs from Expert
Application of Methodology for case
Analyses of results and discussion
Conclusion
Step 1: Gather experts opinion and calculate the average matrix Z
Step 2: Calculate the normalized initial direct-relation matrix D
Step 3: Derive the total relation matrix T
Step 4: Calculate the sums of rows and columns of matrix T
Step 5: Set the threshold value (α)
Step 6: Build a cause and effect relationship diagram
No
Is a cause and effect relationship diagram acceptable?
Yes
The final cause and effect relationship

Figure 4 DEMATEL Methodology

6.2 DEMATEL Methodology and Best Worst Method

To establish and arrive at building energy efficiency factors so that analysis can be conducted. A three-stage framework was presented for designing the research framework to attain the desired research output. First, a hybrid Multi Criteria Decision Making (MCDM) methodology, an amalgamation of two methodologies, Best Worst Method (BWM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL), was considered. A hybrid methodology was considered because the first research stage needed filtering of high-priority attributes. The second stage of research focused on studying the interactions, cause and effect relationships between attributes. Second, the BWM was proposed in this research because the BWM method was best suited with its characteristic property of pairwise comparison and brings out the topmost and least ranking attributes. Therefore, applying the BWM in the first research phase would filter out the least ranking attributes. As a result, only the top-ranking attributes would be investigated further.

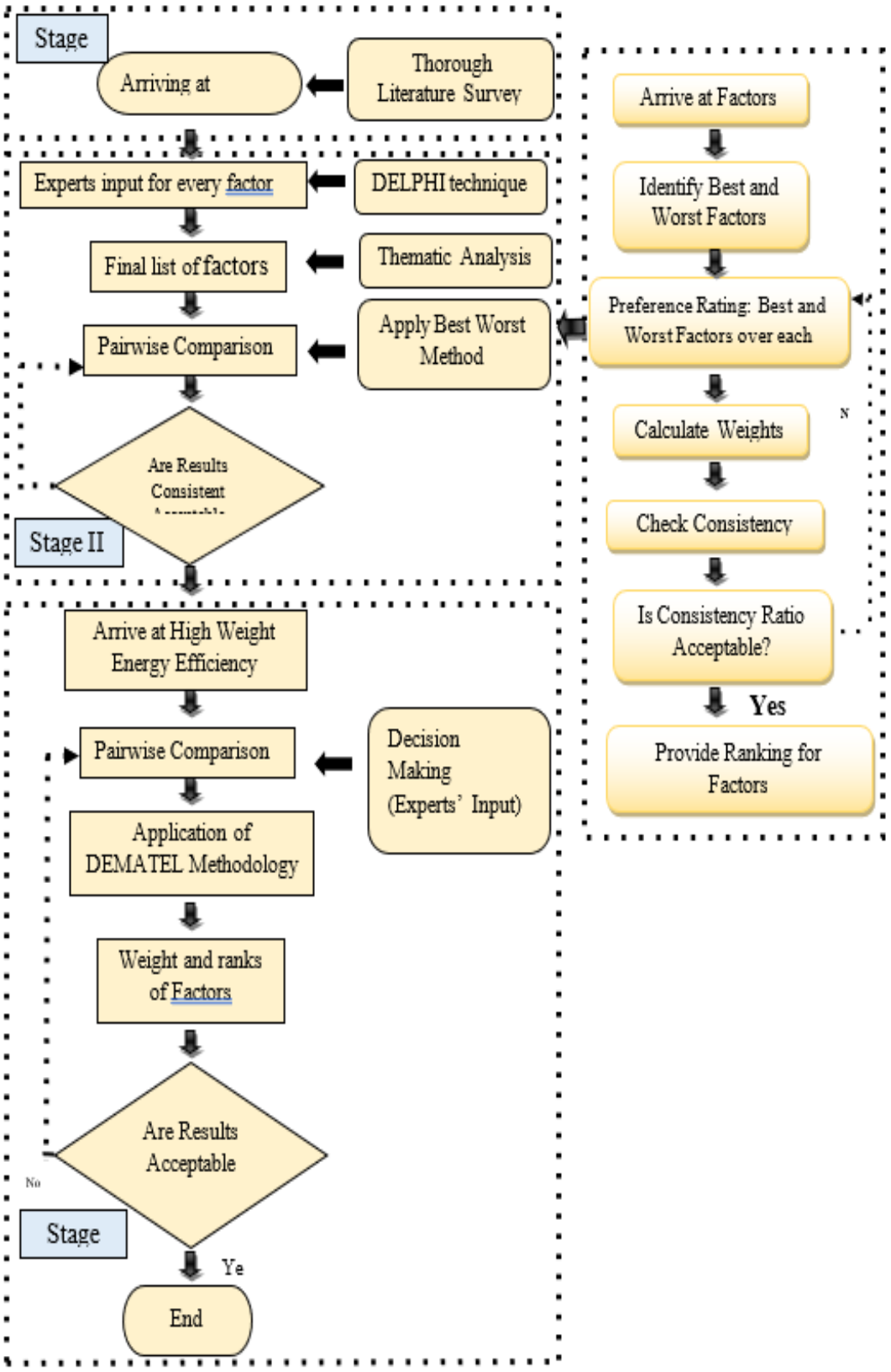

Figure 5 Objective 2- DEMATEL and Best worst method

Figure 5 provides a design of the integrated framework research. In the first stage, the BWM is used; it is one of the novel MCDM methodologies developed by Rezaei in 2015. BWM methodology is applied to this research because among all comparable other MCDM methodologies, BWM has fewer pairwise comparisons and the outcome of the application leads to reliable results. Linear BWM is used in this paper for its simplicity and ease in applying to the research problem, its reliability in results, and its consistency in pairwise comparisons compared with methods like AHP.

7. RESEARCH OUTCOMES AND CONCLUSION

Table 1 is the research outcome of research objective 1 where the sustainability factors necessitate the need for energy efficiency for commercial and residential buildings have been complied, Figure 6 shows the interaction among cause-and-effect group.

Similarly, Table 2 and Table 3 are the research outcome for research objective 2 and 3, which shows the factors for energy efficiency and the factors are also classified into main groups for further analysis. Figure 7 and Figure 8 shows the interaction of the factors using a causal diagram.

Table 1 List of Sustainability Factors

Factor number	Factors
1	Low Operation and Maintenance Cost
2	Promote Renewable Energy production and utilization
3	Energy recovery and Passive Cooling
4	Massing and Orientation to reduce thermal loads
5	Best use of Natural daylight to minimize lighting load
6	Air and Water Quality monitoring and improvement
7	Solid waste reduction and recycling
8	Green and Sustainable material selection
9	Promote Local/Regional materials to utilize and improve the economy
10	Lowering occupant exposure to material toxins
11	Soil protection and flood prevention
12	Reverse Climate change and stabilization

13	Reduce Greenhouse gases and depletion of the ozone
14	Improve Building Asset Value and increase Tenant rate
15	Health and Wellness of Occupants

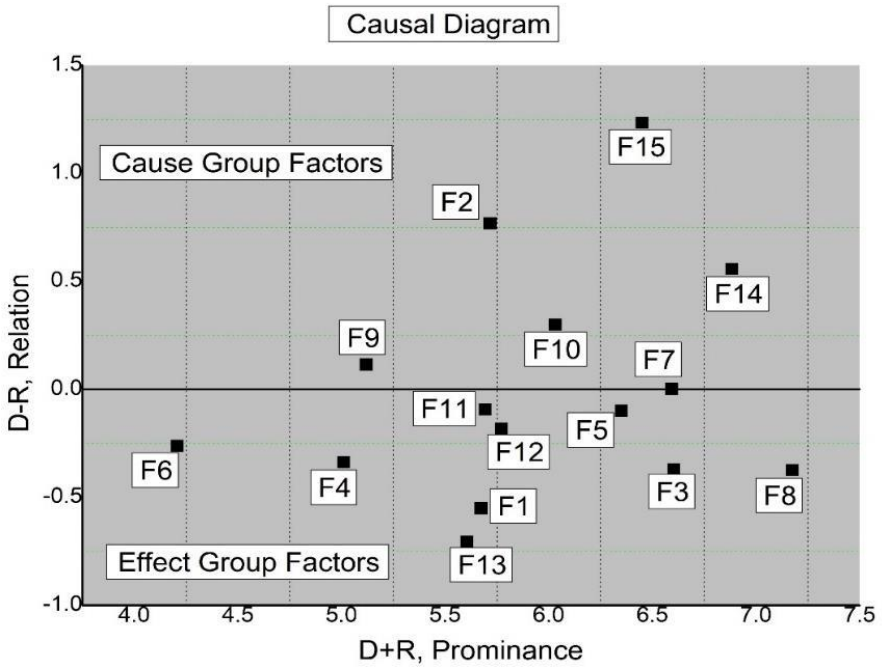

Figure 6 Causal Diagram for Table-1 factors

Table 2 List of energy efficiency Factors for smart cities with classification

MF	Factor No	Factors	Rank
Smartness, MF-1	S1	Smart Meters	11
	S2	Smart Grids	17
	S3	Smart Buildings	7
	S4	Intelligent Systems	8
	S5	Smart Governance	2
	S6	Smart Contract	1
	S7	Renewable energy	18
Sustainability, MF-2	S8	Green Building Concept	16
	S9	Smart Policy	13
	S10	Energy Integration	20
	S11	Smart Commuting	15
	S12	Intelligent energy Consumption	23

	S13	Self Sufficiency	12
Societal, MF-3	S14	Need for energy Security	6
	S15	Social Cohesion	9
	S16	Social Responsibility	10
	S17	Innovation	14
	S18	Urbanisation	5
Technology., MF-4	S19	IoT	25
	S20	Automation	24
	S21	Technological Advancement	22
	S22	Sensors and softwares	21
Building Physiology, MF-5	S23	Smart Materials	19
	S24	Resiliency	4
Behavioural, MF-6	S25	Smart Awareness	3
	S26	Compliance and Guidance	26
Environmental, MF-7	S27	Fossil and Carbon free Society	27
	S28	Sustainable resource management	29
	S29	Mitigate Climate change	30
	S30	Economic Profitability	28

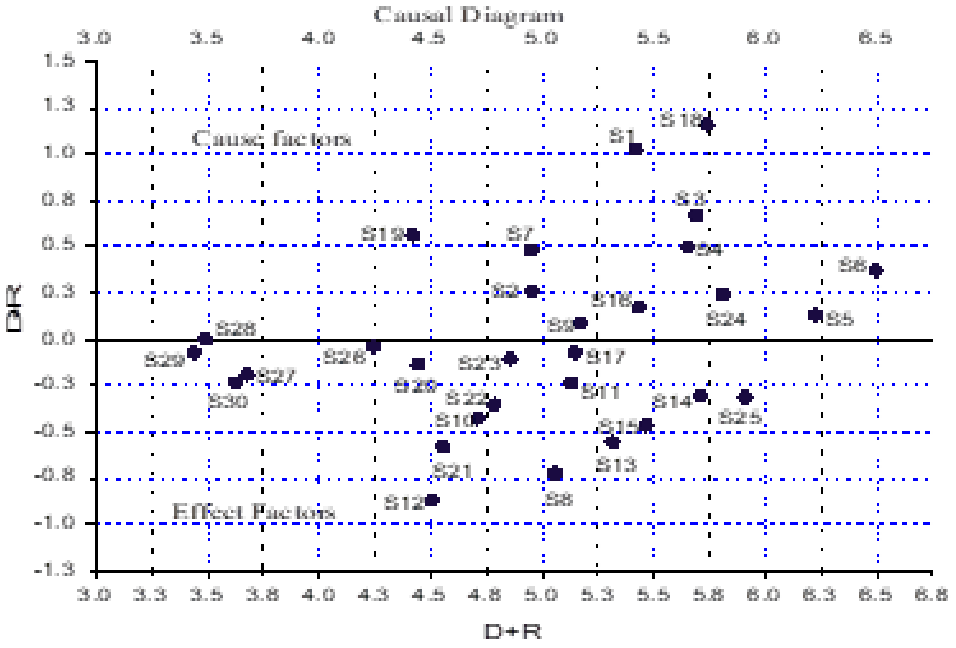

Figure 7 Causal Diagram for Table-2 factors

Table 3 List of energy efficiency factors

Themes	Factor No	Sub factor	Rank
Intrinsic factors	F1	Lighting	12
	F2	Equipment/Devices	8
	F3	IoT/sensors	3
Extrinsic Factors	F4	Wall/Roof types	4
	F5	Floor area	5
	F6	Bldg. orientation	13
	F7	Renewable energy	15
Strategic Factors	F8	Working hours	7
	F9	Energy Policy	6
	F10	Energy Behaviour	14
	F11	Utility Tariff	2
Perpetual factors	F12	Operations/Maintenance	1
	F13	Smart Building Concept	9
	F14	Energy Audit	10
	F15	Real time Monitoring	11

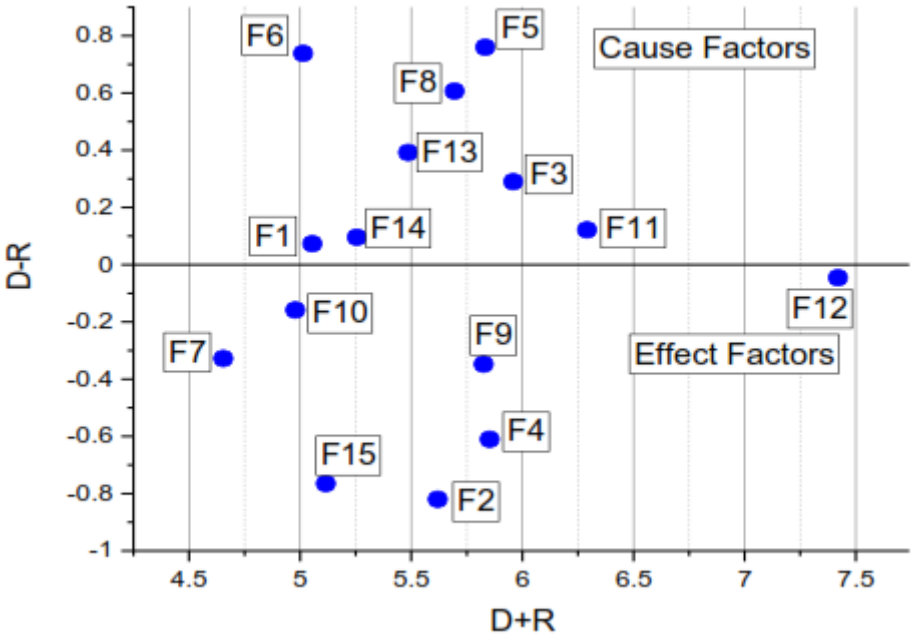

Figure 8 Causal Diagram for Table 3 factors

Table 4 provides the factors that are predominant in international building standards and Figure 9 provides the classification based on the weightage.

Table 4 List of energy efficiency factors for buildings from Energy Standards

Factors	Description
R1	Thermal characteristics and geometry of the building (envelope,
R2	Air-tight structure
R3	Space heating system and hot water supply units
R4	Air-conditioning system(s)
R5	Mechanical and natural ventilation
R6	Built-in lighting system
R7	Design position and orientation of buildings
R8	Passive solar systems and solar protection
R9	Indoor and outdoor climatic conditions
R10	Thermal bridge
R11	Dehumidification
R12	Heat recovery
R13	Passive cooling
R14	Renewable
R15	Electricity for pumps, fans, appliances, and equipment

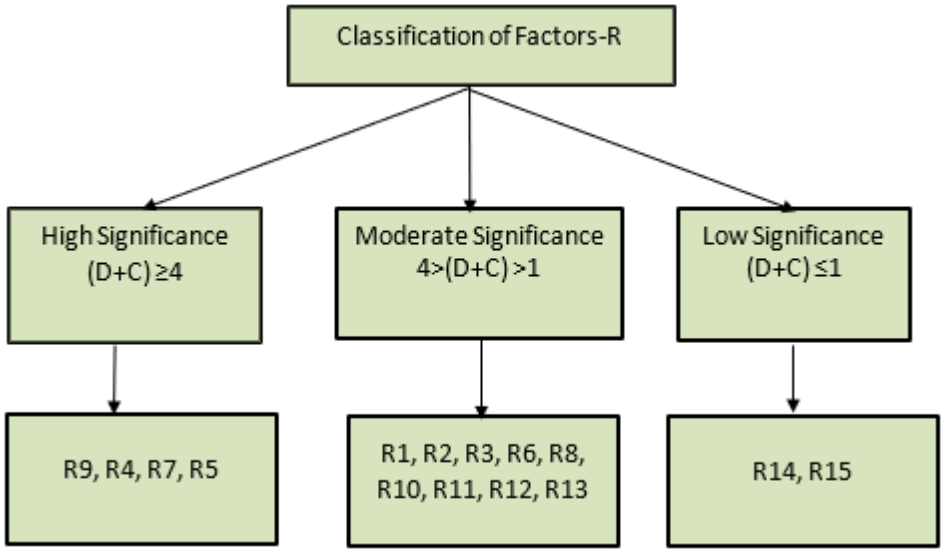

Figure 9 Classification of factors for table 4

8. MANAGERIAL APPLICATIONS

a) This paper can serve as a roadmap for policymakers and managers to control and manage factors responsible for the conservation of energy in urban buildings and communities.
b) The results of this research could be used to decide on a technology for practical application in energy efficiency market.
c) Many energy Efficiency Apps and software developers can take the outcome of this research while developing software, programming an algorithm or developing Apps intended for energy efficiency.
d) The factors can act as a guide for investment into a new technology for energy saving in buildings of residential and commercial sectors.
e) The results provided in this research work can be beneficial to decision makers and energy policy makers. Many building energy efficiency projects could benefit from the cause and effect diagram while applying framework on financial investment, Public private partnership, Building energy Efficiency Code development, formation of legislation etc.

f) The proposed outcome of this research work can benefit energy managers of residential towers in planning building energy operations and Energy management.

9. LIMITATIONS AND FURTHER SCOPE

9.1 The Limitations of this research are,

a) This research is conducted only for Residential and commercial Building Sector-Not for industrial and healthcare sector
b) This research is predominantly done for Indian Subcontinent So The results cannot be generalised to other geographical areas.
c) The complete modeling is based on expert's judgment consulted and opinions based on their experiences. Experiences may differ from one expert to another expert based on different situations.

d) This study in contemporary and is prevalent current trend represented, Future technological advancement may bring further more factors that are not present in this study.

9.2 Further scope of this research

a) This Research is conducted for residential and commercial sector-Further study could be extended to Hospitality sector, Healthcare sector and Industrial Sector

b) This research is specific to Indian sector, further this kind of research could be extended to other geographical areas.

c) In This study MCDM based DEMATEL, Best Worst Method (BWM), AHP and TISM are used,

d) Further. Other Novel MCDM tools Grey DEMATEL, TOPSIS, VIKOR for a comparative study

e) For better refining of results two or more MCDM tools can be combined to obtain comparative and more stringent results.

10. ORGANISATION OF THESIS

Chapter 1: This chapter provides brief information about the introduction of the thesis. It builds a strong research Case and lays the foundation for research in the field of energy efficiency in our daily lives. The importance of energy efficiency and the need for energy conservation is realised. A brief picture of why energy efficiency in residential and commercial buildings should be studied is explained here.

Chapter 2: The problem arising due to high energy consumption in buildings is explained in this chapter. The causes for the research problem are being analysed with respect to society, buildings and the residents of the buildings in the society. The solution for the research problem is being proposed here.

Chapter 3: This chapter provides information about the latest and profound literatures in the field of energy efficiency with respect to buildings. The latest literature of various research organisation is being studied here. The most recent research studies using the same methodology that is being proposed in this thesis is cited. The inference from the

recent literature is being drawn to identify the research gap from the current and contemporary literature.

Chapter 4: The intent of the research is being explained in this chapter. Research objectives are being framed to achieve the intended output of this research. This chapter tries to explain what is being expected from the research and what are its aim and ambitions.

Chapter 5: Because this proposed research is empirical in nature, it is important to understand the research framework. The complete research design is explained in this chapter with the help of a diagram. The complete research is being split into different stages and each stage is explained in detail. This chapter depicts the framework and design to achieve the research objectives.

Chapter 6: The outcome of the case studies conducted is presented here. Various energy efficiency factors that are helpful to save energy in buildings is explained in this chapter. The interaction of various energy efficiency factors is also discussed. The effect and interrelation of society, residents of buildings are being discussed here.

Chapter 7: This chapter includes the summary of the conclusions made after the careful analysis and understanding on the results of the case studies conducted. This chapter concludes the research findings with a set of energy efficiency factors for buildings. The final decision and priorities of various energy efficiency factors are provided here.

Chapter 8: The real-life application of this research outcome is being discussed here. The application of this research to various end users of energy is presented here.

Chapter 9: The limitations of the research are being presented here. A brief solution to overcome the limitations of the research outcome is also being discussed real-life chapter also provides recommendations to continue this research to further stage.

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LIST OF PUBLICATIONS

1. **J. Tippu,** S. Saravanasankar, B. Sankaranarayanan and S. S. Qarnain, Analysis of factors necessitating the need for sustainability in commercial and residential buildings using DEMATEL methodology. In *AIP Conference Proceedings.* **2395** (1) (2021).
2. **J. Tippu,** S. Saravanasankar, B. Sankaranarayanan, S.M Ali, S.S.Qarnain, and K. Karuppiah, Towards Sustainability: Analysis of Energy Efficiency Factors in Buildings of Smart Cities Using an Integrated Framework. *Journal of The Institution of Engineers (India): Series A*, **104** (1) (2023), 223-235.
3. **J.Tippu**, S. Saravanasankar, B.Sankaranarayanan and S.S Qarnain, A Framework for Analysing Energy Consumption Factors in Commercially Built Environments. *Journal of The Institution of Engineers (India): Series A*, **103** (1), (2022), 17-30.
4. **J. Tippu**, S. Saravanasankar, B. Sankaranarayanan, S.M.Ali, V.G.Venkatesh, S.S. Qarnain and M. Sattanathan, Examining energy efficiency requirements in building energy standards: Implications of sustainable energy consumption. *Energy Sources, Part B: Economics, Planning, and Policy*, **17** (1), (2022), 2084184.